Consistency Behaviors of Eggshell Powder Stabilized Black Cotton Soil on Sedimentary Formation of Part of South-Western Nigeria

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Abstract: *Soils which undergo large volume changes with change in water content like black cotton may be troublesome if used for highway or railroad fills or if structural foundations are placed on them. The soil volume changes result in bumps in roads and cracks in structures since the volume changes may not, and usually will not, be equal. The liquid and plastic limits may be used to predict potential problems in soils due to volume changes. However, to obtain quantitative indication of how much change in moisture can occur before any appreciable volume change occurs and to obtain, if volume change does occur, an indication of the amount of change, a shrinkage-limit test should be performed. The black cotton (expansive) soil used in this study was obtained from a borrow pit on the basement complex at Idogo in Yewa South Local Government, Ogun State, South-Western Nigeria. The borrow site lies within the coordinates 6 ^{0}50' 6" N and 2 ^{0}58' 42" N. The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The eggshell wastes were taken from Obasanjo Farms, Ota, Ogun State, Nigeria. The eggshells were milled into powder and then substituted for black cotton soil from 0% to 30% at 10% intervals while 0% eggshell powder substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes, consistency tests were conducted on the composite materials of black cotton (on sedimentary formation) mixed varying degrees of eggshell powder for the determination of liquid limit, plastic limit, etc. It is evidently clear from the results that the percentage shrinkage limit became constant at 30% eggshell powder substitution in black cotton soil on sedimentary formation which is an indication of constancy of volume.*

Keywords: *Black Cotton Soil, Consistency, Sedimentary Formation, Eggshell Powder*

Introduction

Soils which undergo large volume changes with change in water content may be troublesome if used for highway or railroad fills or if structural foundations are placed on them. The soil volume changes result in bumps in roads and cracks in structures since the volume changes may not, and usually will not, be equal. The liquid and plastic limits may be used to predict potential problems in soils due to volume changes. However, to obtain quantitative indication of how much change in moisture can occur before any appreciable volume change occurs and to obtain, if volume change does occur, an indication of the amount of change, a shrinkage-limit test should be performed (Joseph, 1981). This test begins with a given volume of fully saturated soil, preferably, but this is not absolutely necessary, at water content above the liquid-limit. The soil is dried. It is assumed during drying that down at a certain limit value of water content, any loss of water is accompanied by a corresponding change in bulk volume or void ratio. Below this limiting value of water content, no further change in volume occurs with loss of pore water. This limiting value of water content is termed the shrinkage limit. Physically, this means that any moisture changes below the shrinkage limit do not cause soil volume changes. Above the shrinkage limit, volume changes will occur with change in water content. This volume change can be expressed in terms of void ratio and water content (Joseph, 1981). In the case of Idogo black cotton soil, it falls into the category of Ilaro formation which is a typical example of a sedimentary formation that includes both marine and continental deposits. At the time of the deposition of the basal beds, the Eocene shore lay only a short distance to the north of the existing outcrop of the formation and, with the regression of the sea southwards, the marine environment soon gave place to eatuarine and deltaic conditions. Thus within the formation there is a transition from marine to continental sedimentation from south to north and from the lower beds to the higher. Over most of the outcrop, the formation is continental in character and lateral changes in thickness and lithology are rapid and confusing (Jones and Hockey, 1964).

Background Study

The liquid and plastic limits have been widely used all over the world, primarily for soil identification and classification. The shrinkage limit is useful in certain geographical areas where soils undergo large volume changes when going through wet and dry cycles. The potential-volume-change problem can often be detected from liquid- and plastic-limit tests. The liquid limit is sometimes used to estimate settlement in consolidation problems and both limits may be useful in predicting maximum density in compaction studies. In order to place definite, reproducible values on these limits, it was proposed that the liquid limit be arbitrarily defined as that water content at which a part of soil placed in a brass cup, cut with a standard groove, and then drop from a height of 1cm will undergo a groove closure of 12.7mm when dropped 25 times. According to Joseph(1981) several variables affect the liquid-limit test or number of blow required to close the standard groove 12.7mm, including; size of soil pat in brass cup including thickness and quantity; rate of blows which should be 120 rpm; time soil is in cup prior to beginning test blow count and how clean cup is prior to adding soil for the test; laboratory humidity and speed of performing test, type of material used for liquid-limit device base, accuracy of height of fall calibration which should be exactly 1 cm, type of grooving tool either ASTM or Casagrande type, and finally, condition of liquid-limit device either with worn pins, loose connections, etc (Joseph, 1981). The liquid limit is a measure of the shear strength of a soil at some water content. The liquid limit is analogous to a shear test, and has been found that each blow to close standard groove corresponds to 1g/cm^2 of shear strength. Others have obtained similar results so that one might say that the liquid limit represents for all soils a constant shear- strength value of between 20 and 25 g/cm^2 (Joseph, 1981). That the liquid limit increases as the grain sizes of the soil mass decrease is another fundamental observation from research. The plastic limit, besides being the lower boundary range of plastic behavior of a soil, tends to increase in numerical value for decreasing grain sizes. For equal grain sizes, the plastic limit tends to increase for that soil with more scale-like particles. The plastic limit is also a measure of shear strength of a soil. The shear strength of a soil at the plastic limit is a measure of the toughness of the clay; the shear strength of all soils at the liquid-limit is a constant, very nearly. The plastic limit has been arbitrarily defined as that water content of the soil at which a thread just crumbles when it is rolled down to a diameter of 3mm, or approximately 3mm. This test is somewhat more subjective, that is, operator-dependent, than the liquid-limit test since just what constitutes crumbling and what is a 3-mm. diameter are subject to some interpretation. The diameter can be displayed in the laboratory using wire or welding rods for a visual comparison. With practice, it appears that plastic-limit values can be reproduced to within 1% to 3% by laboratory technicians on the same soil (Joseph, 1981).

Methodology

The black cotton (expansive) soil (Figure 1a) was obtained from a borrow pit on the sedimentaty formation at Idogo in Yewa South Local Government, Ogun State, South-Western Nigeria. The borrow site lies within the coordinates 6^0 50' 6" N and 2^0 58' 42" N. The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The eggshell wastes (Figure 1b) were taken from Obasanjo Farms, Ota, Ogun State, Nigeria. The eggshells were milled into powder (Figure 1c) and then substituted for black cotton soil from 0% to 30% at 10% intervals while 0% eggshell powder substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes, details of which could be found in Joseph (1981), consistency tests were conducted on the composite materials of black cotton (on sedimentary formation) mixed varying degrees of eggshell powder for the determination of liquid limit, plastic limit, etc (Joseph, 1981; Ola, (1983); Craig, 1987; BS 1377, 1990; Olarewaju and Tella, 2022; Oarewaju and Oloruko-Oba, 2022; Olarewaju and Falola, 2022).

Figure 1: (a) Black Cotton (Expansive) Soil (b) Eggshell (c) Eggshell Powder

Results and Discussion

The results of consistency tests (liquid limit, plastic limit, shrinkage limit, etc. for various substitutions of eggshell powder in black cotton soil on sedimentary formation from 0% to 30% substitution with 0% serving as control experiment are presented in tabular forms in Tables 1 to 5 respectively. Less emphasis is laid on 5% eggshell powder substitution.

Table 1: Results of Consistency Test on 0% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Sedimentary Formation

Liquid Limit Determination

Moisture can no	IDO 1	IDO 2	IDO 3	IDO 4
Percentage moisture content %	45	42.8	39	35.6
No of blows	13	20	32	43

Plastic Limit Determination

Plastic Limit Determination

Moisture can no	IDO 5	IDO 6
Percentage moisture content %	29.8	27.4

Percentage Shrinkage Limit Determination

Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.5

Table 2: Results of Consistency Test on 5% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Sedimentary Formation

Liquid Limit Determination

Moisture can no	IDO 31	IDO 32	IDO 33	IDO 34
Percentage moisture content %	41.2	40.4	39	35.4
No of blows	16	23	35	48

Plastic Limit Determination

Moisture can no	IDO 35	IDO 36
Percentage moisture content %	28.6	26.2

Percentage Shrinkage Limit Determination

Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.5

Table 3: Results of Consistency Test on 10% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Sedimentary Formation

Liquid Limit Determination				
Moisture can no	IDO 37	IDO 38	IDO 39	IDO 40
Percentage moisture content %	38	37	35.4	34.6
No of blows	12	23	40	48

Plastic Limit Determination		
Moisture can no	IDO 41	IDO 42
Percentage moisture content %	27.1	25.1

Percentage Shrinkage Limit Determination	
Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.6

Table 4: Results of Consistency Test on 20% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Sedimentary Formation

Liquid Limit Determination				
Moisture can no	IDO 43	IDO 44	IDO 45	IDO 46
Percentage moisture content %	35.6	34.4	33	31.6
No of blows	13	23	36	48

Plastic Limit Determination		
Moisture can no	IDO 47	IDO 48
Percentage moisture content %	25.2	24

Percentage Shrinkage Limit Determination	
Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.3

Table 5: Results of Consistency Test on 30% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Sedimentary Formation

Liquid Limit Determination

Moisture can no	IDO 49	IDO 50	IDO 51	IDO 52
Percentage moisture content %	33.8	33	31.6	29.8
No of blows	15	22	34	49

Plastic Limit Determination

Moisture can no	IDO 53	IDO 54
Percentage moisture content %	23.9	20.3

Percentage Shrinkage Limit Determination

Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.3

From the results shown in Table 1, the percentage moisture content varies from 45 to 35.6% in descending order while the corresponding number of blows varies from 13 to 43. The percentage moisture content for plastic limit determination varies from 29.8 to 27.4% in descending order and shrinkage limit is 1.7cm. In addition to this, from the results shown in Table 3, the percentage moisture content varies from 38 to 34.6% in descending order while the corresponding number of blows varies from 12 to 48. The percentage moisture content for plastic limit determination varies from 27.1 to 25.1% in descending order and shrinkage limit is 1.6cm. Furthermore, from the results shown in Table 4, the percentage moisture content varies from 35.6 to 31.6% in descending order while the corresponding number of blows varies from 13 to 48. The percentage moisture content for plastic limit determination varies from 25.2 to 24% in descending order and shrinkage limit is 21.9cm. Finally, from the results shown in Table 5, the percentage moisture content varies from 33.8 to 29.8% in descending order while the corresponding number of blows varies from 15 to 49. The percentage moisture content for plastic limit determination varies from 23.9 to 20.3% in descending order and shrinkage limit is 1.9cm. It is evidently clear from the results that the percentage shrinkage limit became constant at 30% eggshell powder substitution in black cotton soil on basement complex which is an indication of constancy of volume. This is an indication that the optimum percentage substitution of eggshell powder in black cotton soil on sedimentary formation is 30%. This is similar to the submission of Olarewaju and Tella (2022), Olarewaju and Bamisaye (2022) and Olarewaju and Oloruko-Oba (2022). In geo-mechanics/soil mechanics, cohesion limit is that moisture content at which soil crumbs, just stick together while sticky limit is that moisture content at which soil just stick to a metal surface such as a spatula blade. In addition to this, a shrinkage limit is the moisture content below which the soil is non-plastic. Furthermore, liquid limit is that moisture content below which the soil behaves as a plastic material, at this moisture content, the soil in on the verge of becoming a viscous fluid. The liquid limit is sometime used to estimate settlement in consolidation problems (Joseph, 1981).

Conclusion

Consistency characteristics and behaviors of stabilized black cotton soil on sedimentary formation have been investigated. From the results, it is evidently clear from the results that the percentage shrinkage limit became constant at 30% eggshell powder substitution in black cotton soil on basement complex which is an indication of constancy of volume. This is an indication that the optimum percentage substitution of eggshell powder in black cotton soil on sedimentary formation is 30% beyond which no further changes will occur.

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